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ARTIFICIAL DRYING OF AGRICULTURAL PRODUCTS



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The artificial drying or dehydration of some agricultural products is essentially an economic measure accepted by growers, sellers, and consumers for protection of their pocketbooks. Its first practice as a preservative of foodstuffs for family consumption might have been in the Garden of Eden.

The first recorded reference to artificial drying seems to be of a farmer in England, who, in the seventeen hundreds, dried his wheat to prevent spoilage when he wanted to keep it for long periods to obtain a good market price.

With the growth of agriculture in this and other countries, and with the introduction of new methods and equipment for harvesting crops, interest in artificial drying expanded. The value of drying for safe storage and transportation of perishable products and for the reduction of weight in shipping has been recognized for a number of years. The possible use of driers to obtain a high or uniform quality product especially in areas where weather conditions are not suited for natural curing and for the elimination of weather hazards comprise some of its more recent studies.

If sufficiently low-cost methods of drying or dehydration can be developed, they are apt to have a profound influence on the agriculture of the country. For there are many areas advantageously located in

low freight rate zones where large crop yields are possible but where climatic conditions are such that certain crops cannot be cured with reasonable certainty after they are grown.

The application of the direct heat principle to grain and forage drying has probably been the most outstanding development in recent years. However, future research may show the desirability of partial drying of forage in the field or of wilting to reduce the weight in hauling and the total quantity of water to be removed by artificial means. Research dealing with the fundamental requirements involved in the evaporation of moisture from such substances may indicate more economical ways of drying, such as the application of the vacuum principle and still other methods as yet unimagined.

Dehydration, according to Webster, means the "rendering free from water." However, the evaporation of all moisture from agricultural products is not necessarily desirable or practicable. It has been found, however, that by reducing the moisture content of various commodities to between 10 and 25 per cent - depending upon the commodity - that the deteriorating action of such agencies as bacteria, yeasts, moulds, insects, enzymes and probably certain purely chemical reactions, could be arrested. In the case of some products - particularly dried fruits - a preservative such as sulfur dioxide is necessary because of the commercial impracticability of securing the low moisture content necessary and the dried fruit would otherwise lose its attractive and stable form.

The removal of moisture has been divided into three classes: (1) sun drying - where solar heat is made use of; (2) evaporation - where drying is brought about by artificial heat augmented by natural draft;

and (3) artificial drying or so-called dehydration - whereby the drying is accomplished by artificial heat circulated by mechanical draft.

In each case it is a question of converting a certain percentage of the moisture of the product to be dried into water vapor by heat and the carrying away of the water vapor by air currents. The latter case only will be considered in this paper.

Naturally, the higher the temperature, the drier the surrounding air, and the higher the air velocity, the more rapidly would evaporation take place from a free water surface. But with the complex cellular structure and chemical nature of fruits, vegetables, grain, and forage crop tissues, evaporation is retarded to a lower rate than from a free water surface. In some products where conditions are such that surface evaporation exceeds the rate of moisture diffusion to the surface, the surface becomes dry and hard and the moisture escapes with difficulty - a sort of case hardening takes place. Because of this fact, intermittent drying or the use of high humidity air may be necessary with some products.

Utilization of Heat

There are three systems commonly used in the application or utilization of heat for drying agricultural products. With the indirect radiation method, heat is transferred to the product or to the drying air through the intermediate agency of a steam boiler and steam heating coils. When the direct radiation method is used, radiant heat from metal walls or from flues connected with the combustion chamber of a furnace is employed. The direct heat method, the application of

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which is of comparatively recent date, utilizes the products of combustion direct from a coke or oil-burning furnace. The latter method is usually the most efficient and is preferable when the product to be dried will not be injured by coming in direct contact with the products of combustion from the furnace and when fire hazards are not too great. With either the direct or indirect radiation method, almost any available fuel may be applicable but a clean burning fuel is essential with the direct heat method. While the cost of electric energy for heating is prohibitive in drying most agricultural products at the present time, its use for this purpose may be expected to increase with improvements in drying equipment and methods.

## History

While the process of drying certain products of the soil may be considered "as old as the hills," it was not until comparatively recent years that experimental driers were built in this country, the scope of the field enlarged, the need of fundamental investigations realized, and the manufacture of commercial units begun.

The first reference to artificial drying seems to be that recounted in "Horse-Hoeing Husbandry," by Jethro Tull, published in 1829; the actual drying probably being about 1700. This was occasioned by the fact, as related by him, that "a farmer cannot thrive who, for want of money, is obliged to sell his wheat under 5 shillings a bushel, but if he will sell dear, he must keep it when cheap." He goes on to relate that a neighbor of his in Oxfordshire, England, dried wheat for many years by drying it "upon a haircloth in a malt kiln with no other fuel than clean wheat

straw, never suffering it to have any stronger heat than that of the sun. The longest time he ever let it remain in this heat was 12 hours and the shortest time about 4 hours; the damper the wheat was and the longer intended to be kept, the more drying it requires; but how to distinguish nicely the degree of dampness and the number of hours proper for its continuance upon the kiln * * * * * was an art impossible to be learned by any other means than practice."

It should be noted here that the reason for his drying was to prevent spoilage when kept for long periods of time.

The sun, however, is doubtless the oldest drier and is used at the present time, but we cannot always depend upon Old Sol to furnish heat for drying ~~at all times~~, as is necessary. To dry commodities regardless of the weather it was necessary to introduce artificial methods. Probably one of the earliest attempts at artificial drying in the United States was for drying prunes, about 1880. A few years later artificial methods were used in drying walnuts. 1/ Hon. Russell Heath referred to the methods used in artificially drying walnuts in the late eighties, as follows: "In handling the nuts I cure in dry houses by artificial heat, heating sufficient to evaporate the water and set the oil of the nut. When this is done, the nuts will keep sweet for an indefinite time."

The early methods apparently were not entirely practicable as they were used only in a few cases until about 1900, when renewed interest was manifested. At about that time it is stated that the Corona del Mar Ranch at Goleta, California dried walnuts in an old prune drier.

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1/ California Agr. Exp. Sta. Bul. No. 376.

Now driers are perfected to the extent that large quantities of walnuts on the West Coast are artificially dried as well as fruits and vegetables.

The first attempts at artificial drying of forage crops were probably inaugurated by the U. S. Department of Agriculture in 1910, at Haiti, Missouri.[2/] A year later Arthur J. Mason built an outfit at West Point, Mississippi. The Bayley Co. of Milwaukee, Wisconsin, in 1915 built a dehydrator for the McCracken Land Co., of Houston, Texas. The Louisville Drying Machinery Co. of Louisville, Kentucky started experimental work about 1915. From 1915 to 1925 there seemed to be little interest along this line with about the only work going forward being that of Mason and the Louisville Company, each of whom was making improvements on their driers. During 1925 the interest in dehydrators gained momentum and has been getting larger each year. The Louisiana Agricultural Experiment Station was probably the first State experiment station to begin investigational work along this line. The U. S. Department of Agriculture, other State agricultural experiment stations, commercial concerns, and various individuals have each put forth considerable sums of money in an effort to bring about this development.

With the spread of the combine in the humid sections it was found necessary to investigate grain drying. While commercial grain driers had been used for many years in terminal elevators and flour mills, artificial drying of grain has never been practiced to any extent on the farm. This is due in a large measure to the high initial cost and the extreme seasonal demand for the use of grain drying equipment. The introduction of the windrow harvester has made it possible to obtain grain sufficiently

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2/ A.S.A.E. Journal June 1931 - Artificial Dehydration of Forage Crops, by Harold T. Barr.

low in moisture content for safe storage in areas where artificial drying was at one time considered essential for the successful use of the combine. However, the use of grain drying equipment is still of considerable importance to country and terminal elevator operators.

The early attempts to dry corn artificially are probably associated with the development and use of grain driers, as this type of equipment is suitable for drying practically any cereal grain. The drying of seed corn on the cob, however, is not possible with this type of equipment as shelled corn or small grain is held in thin layers in the driers for uniform drying. Several State experiment stations have done considerable work in an effort to develop suitable equipment and methods for handling seed corn during wet seasons.

Commercial grain driers have been used for many years in rice mills in the South and such equipment seems to be essential when the combine is used for harvesting rice. The Department of Agriculture began a study of some of the mechanical and economic factors involved in rice drying in 1929 and tests have been made on both experimental and commercial units. In 1926 investigational work was begun on cotton drying and two types of driers for seed cotton have been developed by the United States Department of Agriculture.

Importance of Drying

There are approximately 12 State agricultural experiment stations with active projects dealing with the artificial drying of farm products. The United States Department of Agriculture, as well as three or four foreign governments, is engaged in investigational work along this line.

The interest which has been taken in this subject has been brought about in some cases by the introduction of new methods and equipment for harvesting grain crops. In other cases it has ensued from a desire to eliminate weather hazards at harvest time, to insure safe storage and transportation of otherwise perishable products, to reduce weight in shipping, or to obtain a high or uniform quality product.

While there is little statistical material available showing the quantity and value of products dried annually in the United States, figures are available which will give some idea of the importance of this method of crop processing. A survey by the Department of Agriculture in 1918 disclosed the fact that there were in this country at least 250 grain elevators equipped with grain driers having a total capacity of about 3,345,000 bushels of grain per day of 24 hours. During the World War 8,905,158 pounds of dried vegetables were shipped to the U. S. Army overseas. In 1929 dried fruit products totaled approximately one billion pounds, of which a considerable portion was dried artificially. During the same year about 3,847,000 pounds of dried peaches and 3,655,000 pounds of dried pears were exported. The average annual production between 1923 and 1927 in pounds of dried product totaled 24,840,000 pounds for apples, 43,120,000 for apricots, 45,000,000 for peaches, and 6,536,000 for pears. In 1925 the production of dehydrated prunes totaled 290,000,000 pounds.

## Developments

The application of the direct heat principle to grain and forage drying has probably been the most outstanding development in recent years.

Some of the early experiments made by manufacturers indicated that in the design and construction of grain driers it was necessary to hold the grain in ~~the~~ them layers or columns for uniform drying and to permit of the circulation of a large volume of air through the grain without excessive power requirements. In seed cotton drying a great deal has been accomplished in the development of inexpensive equipment.

Attention has also been given to the fundamental requirements in drying rice and the effect of different treatments on the quality and condition of the product. For example, it has been found that intermittent drying with short periods of exposure not only reduces the total time required to dry a given quantity of rice but that a higher quality product may be obtained than when the rice is dried in one operation.

Grain drying

Cereal grain with a moisture content not in excess of 14 per cent is usually considered dry enough for safe storage. The moisture content of damp or wet grain when brought to a drier may vary from 14 to 25 per cent but the average may be considered as 18 per cent. On this basis approximately 2 pounds of water must be evaporated in order to reduce the moisture content of one bushel of wheat from 18 to 14 per cent. It is estimated that 1100 B.t.u. are required to evaporate one pound of water from grain. The combustion of coke usually produces about 12,500 B.t.u. per pound. With a thermal efficiency of 50 per cent, which may be considered as an average for grain driers, one pound of coke would be required for each 3 bushels of grain.

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## Grain drying

Cereal grain with a moisture content not in excess of 14 per cent is usually considered dry enough for safe storage. The moisture content of damp or wet grain when brought to a drier may vary from 16 to 28 per cent but the average may be considered as 22 per cent. On this basis approximately 8 pounds of water must be evaporated in order to reduce the moisture content of one bushel of grain from 22 to 14 per cent. It is estimated that 1100 B.t.u. are required to evaporate one pound of water from grain. The combustion of coke usually produces about 12,500 B.t.u. per pound. With a thermal efficiency of 50 per cent, which may be considered as an average for grain driers, one pound of coke would be required for each 5 bushels of grain.

Due to the compact nature of grain, it offers considerable resistance to the flow of air. As the drying air passes through such material, moisture is evaporated, the air is cooled, and the capacity of the air for removing moisture is reduced, causing uneven drying. In order to prevent excessive power requirements and to obtain fairly uniform drying, the grain is held in such a manner that the drying air has to pass through only a few inches of grain.

The quantity of air supplied per unit of time will vary with the different makes and types of driers as well as with the kind of grain dried, but tests indicate that approximately 100 cubic feet of air per minute per bushel of grain is usually supplied in commercial driers. High air velocity is conducive to rapid drying but an increase in air velocity will not always result in a proportionate increase in evaporation of moisture from grain. This is due to the dense structure of the kernels which prevents rapid diffusion of moisture to the surface.

Tests which have been made in commercial driers show that the cost of drying, exclusive of overhead charges, varies from approximately 1/2¢ to 3/4¢ per bushel, with an average reduction in moisture of 5.5 per cent. The overhead cost per bushel of grain will depend almost entirely on the number of bushels dried annually. In other words, the overhead cost involved in drying 10,000 bushels per season would be about twice as much per ~~hour~~ bushels as when a drier handled 20,000 bushels per season.

## Cotton Drying

The physical characteristics of seed cotton, which is the raw product as harvested from the cotton field, are such that temperatures

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Tests which have been made on commercial driers show that the cost of drying, exclusive of overhead charges, varies from approximately 1/5¢ to 1/4¢ per bushel, with an average reduction in moisture of 6.2 per cent. The overhead cost per bushel of grain will depend almost entirely on the number of bushels dried annually. In other words, the overhead cost involved in drying 10,000 bushels per season would be about twice as much per bushel as when a drier handled 20,000 bushels per season.

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The chemical decomposition of seed cotton, which is the raw product as harvested from the cotton field, are such that temperatures

must be limited to below the boiling point of water in order to prevent injury to the delicate fibers. The Bureau of Agricultural Engineering secured a public patent on a process which has become generally known as "the Government process", which embodies the following principal features: first, temperature is maintained preferably between the limits of 160° to 200° Fahrenheit; second, the volume of heated atmosphere employed per pound of damp seed cotton is varied between 40 and 100 cubic feet; and third, the period of exposure or time in which the damp seed cotton is subjected to the continuous flow of heated atmosphere varies between 45 seconds and 3 minutes.

The specific gravity of the seed cotton has permitted the Bureau to develop a vertical tower-type of drier which has 17 or more horizontal sheet metal floors and through which the cotton is blown by means of a continuous blast of heated atmosphere conforming to the process requirements. This type of drier employs only standard cotton ginning fans and other apparatus well known to the trade, and during the past season of 1931 approximately 10,000 bales of damp seed cotton have been very successfully dried at commercial ginneries in the long staple regions of the Mississippi Delta. Such a widespread interest has been manifested in this vertical drier that the present indications point to the construction of at least 100 during the coming season. Several of the more enterprising manufacturers of cotton ginning equipment have fitted up to sell this Bureau design ~~and~~ a drier to the trade [illegible] at a very reasonable price. It is interesting to note that the capacity of this drier is approximately 9,000 lbs. of damp seed cotton per hour and that the cost of this drier

is approximately only one-third the price charged for other types of commercial driers having a similar capacity.

## Forage Drying

Forage is bulky and seventy to eighty per cent of the weight of crops, such as alfalfa and grasses, cut for hay, is water, which means that approximately two tons of water must be evaporated to obtain one ton of dry material. It is estimated that approximately 1100 B.t.u. are required to evaporate one pound of water from forage plants. The combustion of coal produces approximately 14,000 B.t.u. per pound and fuel oil about 19,000 B.t.u. If the thermal efficiency were 100 per cent, 315 pounds of coal or 232 pounds of oil (31 gallons) would be required. As 50 per cent may be considered as an average overall thermal efficiency, 630 pounds of coal or 62 gallons of oil would be required.

Then comes the problem of carrying off the moisture. Atmospheric air always contains some moisture. The volume of air to carry off the evaporated moisture as well as that resulting from combustion must be calculated and the amount of moisture in the air taken into account. A rough approximation indicates that about 2 million cubic feet of air measured under atmospheric conditions would be required to carry off the moisture in obtaining one ton of dry forage. The exact amount would of course depend to a large extent on the type of drier and temperature of the drying air.

The design of forage driers has in general followed conventional lines. That is, the principles involved are quite similar to those

which have been used for many years in other industries. Of course there have been improvements and modifications in the adaptation of such equipment to forage drying conditions, but practically all of the driers may be classified either as of the revolving ~~drier~~ drum, tray, or apron conveyor type. With the revolving ~~drier~~ drum type the forage must be chopped into short pieces, whereas with the apron conveyor or tray type it may be dried whole. A high drying air temperature, short period of exposure, and rapid drying are characteristics of the drum drier as used for forage. The characteristics of the tray and apron conveyor types are: low temperature, long period of exposure, and slow drying.

The simple drum drier usually consists of a drum or cylinder from 6 to 8 feet in diameter by 40 to 50 feet in length, mounted with its axis horizontal and in such a manner that it can be revolved at the desired rate of speed. Where the direct heat method is used, an oil or coke-burning furnace is installed at one end and a dust collector, or chamber, for receiving the dried forage, at the opposite end. In some cases the dried material is removed from the dust collector by a conveyor, whereas in other cases the fan used for drawing the products of combustion through the drier is used for the purpose. The green forage is fed into the drier at the furnace and as the drum revolves, the material is picked up by flights mounted on the inside of the drum. Each time the material is picked up and allowed to fall through the stream of hot gases passing through the drum, it is moved towards the discharge end of the drier. In some cases this type of

which have been used for many years in other industries. Of course there have been improvements and modifications in the adaptation of such equipment to orange drying conditions, but practically all of the driers may be classified either as of the revolving drum, tray, or steam carrier types. With the revolving drum type the orange must be chopped into small pieces, whereas with the steam carrier or tray type it may be dried whole. A high drying air temperature, short period of exposure, and rapid drying are characteristics of the drum drier as used for orange. The characteristics of the tray and steam carrier types are: low temperature, long period of exposure, and slow drying.

The simple drum drier usually consists of a drum or cylinder from 4 to 8 feet in diameter by 20 to 50 feet in length, mounted with its axis horizontal and in such a manner that it can be revolved at the desired rate of speed. Where the direct heat method is used, an oil or gas-burning furnace is installed at one end and a dust collector, or cyclone, for receiving the dried product, at the opposite end. In some cases the dried material is removed from the dust collector by a conveyor, whereas in other cases the fan used for drawing the products of combustion through the drier is used for the purpose. The green orange is fed into the drier at the furnace end as the drum revolves, the material is picked up by flights mounted on the inside [illegible] face. Each time the material is picked up and allowed to fall [illegible] mass of hot gases passing through the drum, it is moved [illegible] other end of the drier. In some cases this type of

drier consists of three drums, one within the other, and arranged in such a manner that the forage must pass through each drum before it is discharged from the drier.

All apron conveyor driers are similar in that the forage is conveyed through the drying chamber on an endless screen wire conveyor. Provisions are usually made for uniform distribution of material on the apron. In one case this is done by a ribbon forming machine, whereas in another case the forage is compressed slightly by a plunger which forms a mat of uniform density and thickness. The products of combustion are drawn from the furnace, mixed with outside air in a mixing chamber, and forced through the hay by one or more fans.

In one type of tray drier the green forage is loaded on trays by hand, with forks, allowed to dry and then removed to make way for a fresh charge of green material. In order to eliminate some of the hand labor involved and to facilitate rapid drying, experiments have been made in which the forage is loaded in trays, the trays moved through the drying chamber, and then dumped by mechanical means.

Due to the large number of variables involved, it would be impossible to make any definite statement regarding the cost of drying forage artificially. However, tests made on several commercial driers show that the cost of power and fuel may vary from approximately $3.50 to $9.85 per ton of dry forage when the moisture content of the forage is reduced from approximately 70 to 12 per cent. When labor was included the total operating cost varied from approximately $4.80 to $12.35 per ton of dry forage.

The actual operating cost of drying forage will depend in part upon type of drier used, condition of the forage to be dried, skill of the operator, and weather conditions. No definite statement can be made as to the relative efficiency of different types of driers. In general, the simple drum drier can be operated with less power and fuel than other types. However, some of the large apron conveyor driers may be operated at a lower cost per ton of forage dried than the revolving drum type. The overhead expenses are, as a rule, much higher on the apron conveyor type because of the high initial cost, which tends to increase the total cost of drying. The initial cost of drum drier installations may vary from approximately $5,000 to $10,000, whereas the apron conveyor types may vary from $10,000 to $30,000.

Methods and equipment used in harvesting the crop and getting the material to the drier, as well as the efficient utilization of labor in the field and at the drier, also have a considerable influence on cost of producing artificially dried forage.

In making a comparison of the performance of different types of driers, the kind of material dried should be given consideration. Succulent plants with small stems and leaves, such as meadow grasses, clovers, and alfalfa, frequently will dry more quickly and uniformly than soy beans and other similar rank-growing plants.

One modeof appraising the value of artificially dried forage is to compare the market value of alfalfa hay by grades. In this connection it is assumed that the highest possible grade of alfalfa hay, which is U. S. No. 1 extra leafy, could be obtained by artificial drying provided, of course, that the forage was cut at the proper time and that it was not injured during the curing and handling

process. In addition, it is assumed that the average grade of alfalfa hay sold on the market is U. S. No. 2. On this basis the average difference in price of carload lots on the Kansas City market, and U. S. No. 1, extra leafy alfalfa hay, from August to December, in 1927, was $6.65. In 1928 the difference was $7.45 for the same period. While insufficient data are available to compare the market value of these two grades in 1929 or 1930, the difference was approximately $5.50 in 1931. From this it would appear that the actual market value of artificially dried hay might be expected to bring from $5.00 to $7.00 per ton more than the average alfalfa hay which is placed on the market.

While we have no test data to show the difference in nutrient value of the different grades of hay, the opinion seems to be that the price difference is justified.

Research problems in forage drying

Forage is a product of relatively low market value in comparison with other agricultural products which are dried artificially. It is bulky and has a high moisture content when cut. Unless such feed can be produced at a lower cost with an artificial drier than by natural drying, or unless a product of much superior quality can be obtained, there appears to be a limited field for the use of forage driers.

In view of the rather uneconomic aspects of the problem, it appears that activities should be concentrated on an effort to increase the efficiency of driers, reduce the overhead cost by simplifying the equipment, and in producing a high quality product, the increased value of which will compensate for the cost of artificial drying.